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ScienceDirect
Energy Procedia 68 (2015) 45 – 52
Energy Procedia

2nd International Conference on Sustainable Energy Engineering and Application, ICSEEA 2014

Effect of rim angle to the flux distribution diameter in solar parabolic dish collector

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Abstract

Solar energy application through parabolic dish collector is promising finite green energy such as electric generation. A study of solar parabolic dish collector had been carried out on the geometry and flux distribution at focal region. Rim angle is an important parameter to determine the imaging and non-imaging diameter of the flux radiation. The imaging and non-imaging geometry were simulated using the ray tracing simulation and 2D computer aided drawing. The flux distribution was then tabulated on coordinated graph to obtain the diameter. The imaging diameters are in the ranges of 17mm to 286mm while the non-imaging diameter values are in the ranges of 23mm to 345mm. Reflex rim angle yields small imaging and non-imaging diameters which values are 37 mm and 53mm respectively. An acute rim angle yields larger imaging and non-imaging diameter. It shows that the optimum parameter of the parabolic dish is important to achieve high intensity of focus point.

Peer-review under responsibility of Scientific Committee of ICSEEA 2014

*Keywords:*Solar parabolic dish; flux distribution; imaging and non imaging diameter; rim angle.

1. Introduction

Solar parabolic dish converts the thermal energy of solar radiation to mechanical energy. The parabolic dish is mainly used to concentrate solar radiation for low, medium and high temperature usage [1]. Following the shape, a solar parabolic dish have concentration ratio in between 600 to 2,000 and can achieved temperature of 1,500°C [2].

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Peer-review under responsibility of Scientific Committee of ICSEEA 2014
doi:10.1016/j.egypro.2015.03.231

The parabola has a unique property aims to collect solar radiation and concentrated to a small area which increase the density several hundred times. An approximately parabolic surface is produced by putting reflector strips of a chosen width on the parent parabola. The definition of an imaging concentrator is one that will produce an image at its focus of the light sources situated at a large distance from it [3]. In this paper, the study of flux distribution at focus point is important to know the concentration ratio of the solar collector determines the intensity of the solar radiation received by the receiver. The focal region area is smaller than that of the reflective surface capturing the energy, thus allowing for the same amount of radiation that would have been spread over a few square meters to be collected and concentrated over a much smaller area allowing for higher temperatures to be obtained [4].

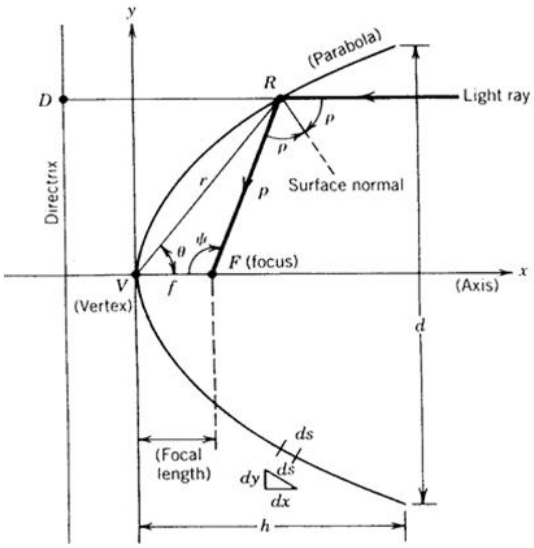

Fig. 1. The parabolic geometry.

1.1. Ideal parabolic dish

In Fig. 1, a parabola is the locus of a point that moves so that its distances from a fixed line and a fixed point are equal. The fixed line is called the directrix and the fixed pointF, the focus. The line perpendicular to the directrix and passing through the focus F is called the axis of the parabola. The basic equation of the parabola is:

$$y^2 = 4fx \tag{1}$$

where f is the focal length and x is the distancefrom the vertex to the focus [4]. The focal length of the parabolic dish can be derived from Equation 1.

$$f = \frac{D^2}{16d} \tag{2}$$

where f is focus point of the dish, D is diameter of the dish and d is depth of the dish [5]. The analysis is covering the projected areas of both the sun and the concentrator. Bundles solar flux from each solar elementare made incident with a unique incidence angle on each of the concentrator elements. This technique can be reasonably applied because the simple receiver geometry allows a closed form mapping from the concentrator to the receiver.

1.2. Imaging and non-imaging flux distribution

In focus point area, the solar flux is divided into imaging and non-imaging flux. Minimum diameter of focal region area is needed in order that all the solar flux is concentrated within the region. The key point to achieve high concentration ratio is to know the flux distribution at the focal region [6]. The imaging radiation has high temperature due to the dense flux in the area. Diffuse solar flux mostly creating non-imaging area. Correct focus point is vital for accurate reading and heat collection. The parabolic dish design must be such way that yields small focus point because it will give higher temperature. The imaging diameter shall smaller in area resulting high temperature upon focusing the solar radiation. Such parabolic dish should have good concentration ratio when it is parallel with the sun otherwise the solar radiation will be scattered.

2. Methodology

2.1. Modelling

Parabolic dish collector modelling is important to able the evaluation of several parameters that affect the rim angle of the parabola [7]. Alterations in the collector are easily made and evaluated. A parabola dish is modelled in Tonatiuh software as in Fig. 2. The parabola dish later is subjected to few parameters. The parameters are diameter and the focal length. The sun plane and the receiver are based on coordinate set. The parabola dish can be modelled which any sun shape.The parabola is drawn from the simulation interface. The parabola then subjected to the sun collection environment. The basic parameter of the parabola is inserted before the simulation was run. Furthermore, the parameters are vital to ensure the parabola is in the correct condition before running the simulation.

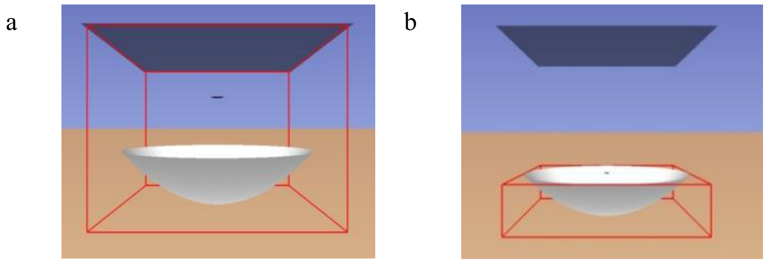

Fig. 2. Model of parabola dish in ray tracing simulation. (a) 10 meter diameter; (b) 20 meter diameter

2.2. Ray tracing

Ray tracing simulations are very effective for design and optimization of parameters in parabolic dish collector [8]. In this research, ray tracing method is used to simulate the sun radiation in the parabolic. Diameter is subjected from 1 meter to 20 meters. The focal length is measured by fraction of the dish diameter as in Fig. 3. After all the parameters had been set, the ray tracing is executed. The incident flux at the receiver is mapped by two dimension coordinates mapping. A geometric optics formulation is used in the present analysis over the projected areas of both the sun and the concentrator. The reflection from each concentrator element is mapped analytically onto the surface of the cylindrical receiver. In the following analysis, concentration on the receiver surface is first calculated under the idealized conditions of collimated solar incidence, aligned with the axis of a perfect-surface concentrator. An arbitrary incidence angle is then used to derive a general mapping of the solar radiation [9].

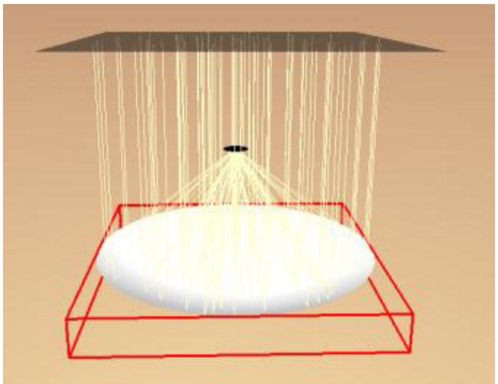

Fig. 3. The ray simulation of parabolic dish.

3. Result and Discussion

3.1. Flux distribution at focal region

The sun radiation is plotted in the exactly as graph shown in Fig. 4. The flux distribution of the radiation can be determined the imaging and non-imaging focal region of the respective parabolic dish parameters. The flux coordinate can determine the intensity of the flux as shown in figure below. The smaller parabolic, 1 meter diameter has smallest imaging flux diameter of 17 mm and non-imaging flux diameter in other hand has smallest flux diameter of 23 mm. Larger parabolic diameter (15 meter and above) has much larger imaging and non-imaging flux distribution. The imaging flux distribution for largest 20 meter parabolic dish can be read 286.8 mm for imaging diameter and 345.0 mm for non-imaging diameter.

The diameter of the imaging and non-imaging can determine the size of the focal receiver for future development of parabolic dish collector system. This could be the reason that most of the radiation is captured through an optimum opening size of heat receiver. The diameter of the flux is determining the opening aperture of the receiver so that it is large enough to receive most of the solar radiation.

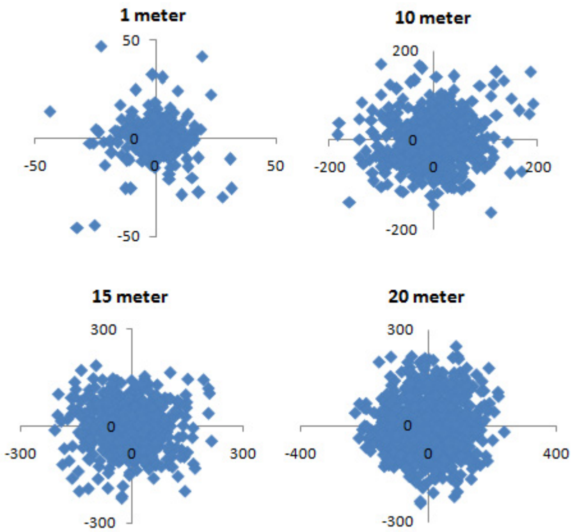

Fig. 4. The flux distributions are mapped in coordinated graph.

3.2. Rim angle

The rim angle affects the incoming radiation of sun radiation and the manufacturing of the parabolic dish. Basically, the imaging and non-imaging diameter are changing according to different rim angles. Therefore, the geometric manipulation for each cases and the flux distribution is varied. After the image diameter is known, the rim angles are tabulated in Table 1 below. Table 1 below shows the rim angle, imaging diameter and non-imaging diameter for 1 meter parabolic dish. The rest of the parabolic dish diameters were tabulated following Table 1. The higher focus point of the parabolic dish, it will yield higher value in both rim angles of imaging and non-imaging diameter. The value of rim angles is decrease when the focus point is increase. This is due to geometric expression of the parabolic dish. There are small differences of the value of the rim angle.

Table 1: Rim angles, imaging and non-imaging diameter of 1 meter parabolic dish.

focus point [mm]	θ rim ideal	diameter image [mm]	diameter non image [mm]	θ rim image	θ rim non image
250	180.00	8.00	22.04	180.00	180.00
500	106.26	6.60	12.80	105.90	105.55
750	73.74	13.60	22.80	100.20	99.72
1000	56.14	8.32	12.74	78.64	78.47
1250	45.24	4.00	12.60	64.52	64.21
1500	37.84	16.00	20.00	54.09	53.97

Imaging and non-imaging rim angles are generated from the 2-D computer aided designing software to trace the size of aperture of the focal spot as in Fig. 5. Gaining the diameter of the aperture, the angle can be concluded in the software and tabulated further as shown in Table 1. The value of the focal length is in the range of 250 mm to 270 mm for both imaging and non-imaging focus point. The focal length is depending on the size of the parabolic dish which available in the simulation. The rim angle for both imaging diameter and non-imaging focus point is decreasing as the focal length increasing. Each parabolic dish has respective geometry characteristic in order to obtain the imaging and non-imaging diameter of the flux distribution. Small parabolic dishes with diameter of 1 meter until 5 meter have rim angle from 37° to 254°. Large parabolic dished with diameter 15 meter to 20 meter have rim angle from 38° until 255°. The 1° difference was due to increasing of imaging and non-imaging flux distribution diameter at focus point.

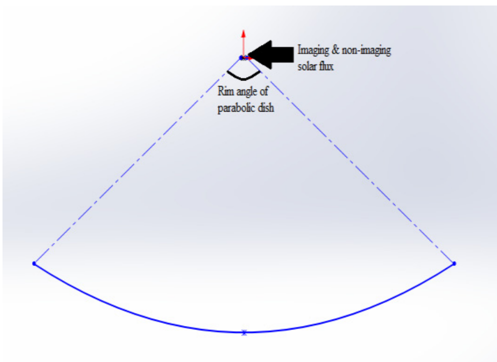

Fig. 5. 2-D computer aided drawing

3.3. Relationship between rim angle and imaging diameter

The imaging diameter is increase when the rim angles increase. Fig. 6 shows the decrease of imaging diameter until the rim angle reaches 50°. The one meter parabolic dish has lowest imaging diameter which is 37.2 mm at 18° of rim angle. The twenty meters parabolic dish has higher imaging diameter which is 297.8 mm at 18° of rim angle. This was happening at the beginning of the rim angle opening of the parabolic dish. The imaging diameter is varies at the 90° of the opening of the rim angle. The imaging diameter varies at this point is due to the aperture difference of the image and the height of the focal length from the centre of the parabolic dish. When the focal length value is lower than the parabolic diameter, the rim angle will produce a reflex angle. Reflex rim angle produce uneven imaging diameter. Obtuse rim angle is starting to produce better imaging diameter. At obtuse rim angle, 18 meter parabolic dish produce 233 mm imaging diameter while 1 meter parabolic dish produce 25 mm imaging diameter. Obtuse rim angle produces slightly even imaging diameter. The relationship between obtuse rim angle and imaging diameter is almost linear.

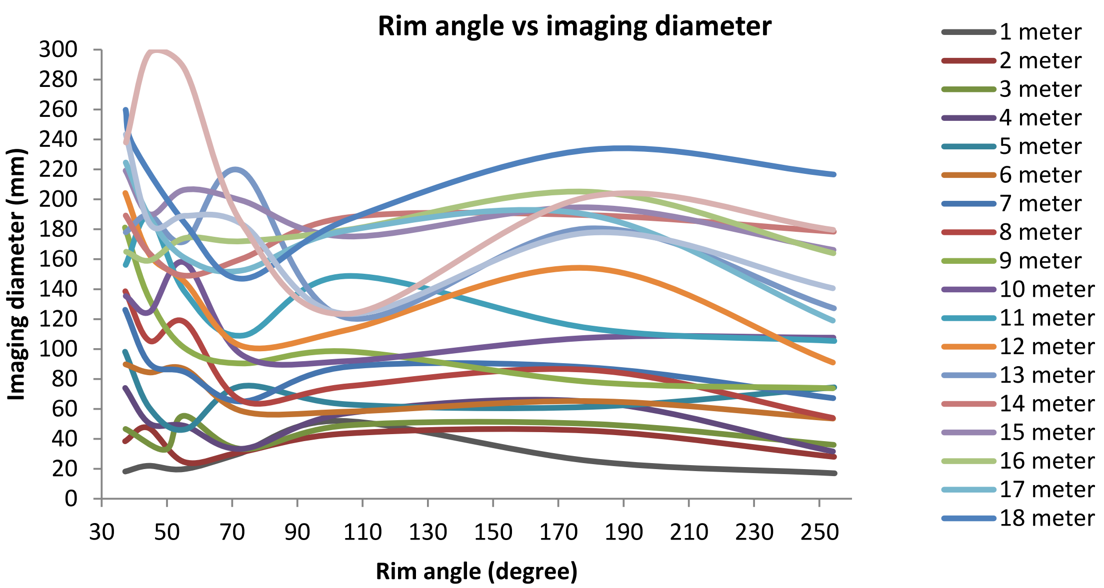

Fig. 6. Effect of imaging diameter with the rim angle

3.4. Relationship between rim angle and non-imaging diameter

The non-imaging diameter is increase when the rim angles increase. Fig. 7 shows the decrease of imaging diameter until the rim angle reaches 50°. The one meter parabolic dish has lowest imaging diameter which is 53 mm at 30° of rim angle. The twenty meters parabolic dish has higher imaging diameter which is 345 mm at 30° of rim angle. This was happening the value of the rim angle is acute at the opening of the parabolic dish. The non-imaging diameter is varies at the 90° of the opening of the rim angle. The non- imaging diameter varies at this point is due to the aperture difference of the image and the height of the focal length from the centre of the parabolic dish. When the focal length value is lower than the parabolic diameter, the rim angle will produce a reflex angle. Reflex rim angle produce uneven non-imaging diameter. However, obtuse rim angle is still producing uneven non-imaging diameter. At obtuse rim angle, 18 meter parabolic dish produce 324 mm imaging diameter while 2 meter parabolic dish produce 38 mm imaging diameter. Obtuse rim angle produces slightly uneven non-imaging diameter. The relationship between obtuse rim angle and imaging diameter is not linear.

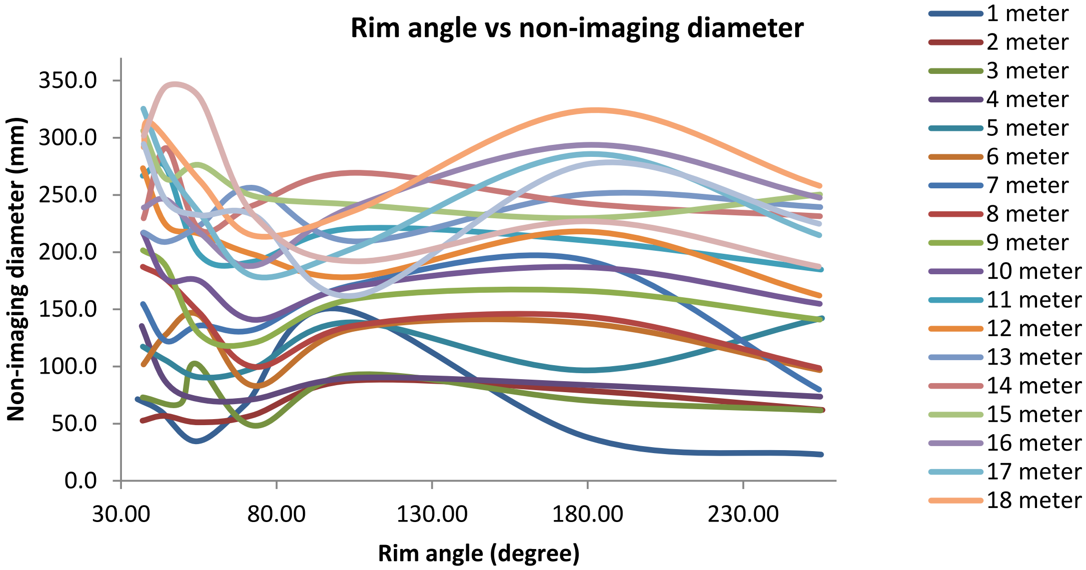

Fig. 7. Effect of non-imaging diameter with rim angle.

4. Conclusion

The rim angle determines the focal length of the parabolic dish. It is essential to know the value of rim angle to optimize the amount of solar flux collection. The angular deviation of the reflected rays is scatted due to finite size of the incoming incident on the focusing power of the parabolic collector. Bundles of rays of solar heat flux from each solar element, in turn, are made incident with a unique incidence angle on each of the concentrator elements. The efficiency of the parabolic dish is relying on the flux intensity of the focus point. The focal region area affects both optical efficiency and the concentration ratio of the solar parabolic dish. Correct focus point is vital for accurate reading and heat collection. The rim angle gives true value of concentrated radiation because considering optical losses from the reflecting of the solar radiation. Future study can be conducted to relate the flux intensity and the efficiency of the solar radiation collection.

Acknowledgements

The authors would like to thank the Faculty of Mechanical Engineering, Universiti Malaysia Pahang for the support.

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